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ABSTRACT

Various aspects of automation are explained to differentiate it from technology and mechanization and to show the difference between using equipment to help humans and using equipment to replace humans. Five reasons are given for engineering psychology to focus its attention on automation. Automation issues in a number of areas are discussed, including command and control systems, robotics, combat aircraft, air traffic control, nuclear power plants, and offices of the future. (JN)

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Automation and Engineering Psychology: A Look to the Future

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PREFATORY NOTE

This paper was presented at the 89th Annual Meeting of the American Psychological Association in Los Angeles, California, in August 1981 by Dr. H. McIlvaine Parsons. It was an Invited Address to APA Division 21, the Society of Engineering Psychologists. Dr. Parsons, who is Manager, HumRRO Human Factors Projects, is a Fellow of the American Psychological Association and a Past President of the Human Factors Society and of the Society of Engineering Psychologists.

AUTOMATION AND ENGINEERING PSYCHOLOGY: A LOOK TO THE FUTURE

H. McIlvaine Parsons

It seems odd that engineering psychology has so rarely confronted automation as something to discuss or investigate. This may be because automation often conjures up organizational or societal impacts rather than its relationships with human performance. It may be because any inquiry into some particular automation requires studying its advantages and limitations as well as those of the humans whose performance is being or might be automated, and engineering psychologists are accustomed to concentrating on humans. But my message today is that engineering psychology should pay more attention to automation, now and in the future—and not just to find out whether members of Division 21 face technological unemployment in an automated world.

I intend to explain what I mean by automation, why it has become an increasingly important topic for engineering psychology, and what we should do about it. But first let me indulge in some reminiscences.

One of these is very recent. Last week I was cruising the coast of Maine in a sailboat and went between boat and shore in a dinghy either by outboard motor or by rowing. Unaided human progress on the surface of the water occurs by swimming. Should oars, sails, or outboard be viewed as automation? Further back in time by thirty years, I gave my first invited talk on engineering psychology and automation at a meeting of a small professional group in New York City. Alcoholic beverages were served from the start. I spoke the first three sentences in person, explaining I was about to demonstrate the optimal allocation of functions between humans and machines, and turned on a tape recorder for the rest of my talk. Then I was able to devote myself to the function of drinking; my audience was not amused. I won't try that today.

In the early fifties, the laboratory where I was working, at Columbia University, was developing the first computer-based system for air defense. It was an analog-computer-based system in which an Air Force controller tracked the radar signals from a hostile aircraft by placing a cursor, with a control stick, over two successive blips so the computer then generated a track. The computer also produced a vector for a friendly interceptor aircraft to fly from its base to intercept the hostile. This innovative system, eventually installed throughout the United States, was intended to help controllers handle more interceptions overlapping in time than they could with the manual system of tracking with a grease pencil and calculating vectors in their heads. In both laboratory and field studies I showed that this automation worked (Parsons, 1954a,b). But was it better?

It became clear that with sufficient training, a controller could calculate vectors in his head with the precision needed. The engineers who had designed the system had assumed otherwise. There was another problem. The computer calculated a direct collision course to interception, but the interceptor pilot had to acquire the target on his airborne fire control system at a point from which he could make a beam (90-degree) intercept. Toward the end of the interception, the controller had to change the computer-derived course so the interceptor would reach this point—an in-the-head calculation more difficult than the computer's earlier vectoring. I recall developing and testing an effective rule-of-thumb procedure for a controller to use (Parsons, 1954c). I also

discovered that one of the Air Force controllers serving as experimental subjects devised a procedure whereby he could track a target better manually than the computer could—even through noise. I found as well that although all my subjects were highly qualified, they varied greatly in their performances on both the manual and automated system; indeed, individual differences exceeded mean differences between the systems. These were lessons about tradeoffs between automation, human skills, training, procedural improvement, and personnel selection.

There was also a lesson about the implementation of automation (Parsons and Sciorra, 1954). The controller's tracking stick was simply a combination of directional control and switch that started a motor that moved the cursor at a constant speed toward the blip. Despite my laboratory's pleas, the system was built and installed with a motor that moved the cursor so fast that the controller had to spend a vast amount of time jiggling the stick to get the cursor over the target, time he was supposed to spend running another intercept. The interception workload the controller could handle wasn't increased much after all.

I learned more about automation when, at the System Development Corporation, I had to develop and install a training program for electronic counter-countermeasures in the SAGE air defense system (Parsons, 1960). SAGE was a digital-computer based system that replaced the analog system. Although it, too, incorporated great engineering ingenuity, again there were misconceptions about what automation, rather than a human operator, could accomplish. Its designers assumed the computer could initiate and maintain a track of aircraft automatically. But in the world of operational reality—which included radar signals from other sources than targets—it turned out that an operator had to initiate tracks and make sure they stayed with the processed radar signals of the aircraft, reinitiating them if the track and the aircraft parted company; the computer could not make the discriminations from noise as reliably as humans. Nor could it, as planned through triangulation, establish the location of an aircraft whose distance from a radar couldn't be determined due to jamming. A field study I ran showed that electronic countermeasures had to be countered out at the radars, with human interventions (Parsons and Seiden, 1959). It had also been assumed that the SAGE computer could assign weapons automatically but again this proved a bit of wishful thinking. I cite these instances because the limitations of automation in system operations have seldom been documented, and we may be able to learn something from the past about automation in the future, or at least about proposals and projections. SAGE was aptly named the Semi-Automatic Ground Environment.

Among the weapons it assigned and controlled was the BOMARC, an unmanned interceptor built by Boeing. It was never a great favoriate among pilots, any more than other RPVs (Remotely Piloted Vehicles) among the former pilots who are now Air Force generals, and only a small number of BOMARCS were produced and installed. One of the criteria for deciding whether to automate something is how well it will be accepted by those destined to use it. Technological unemployment is resisted not just by industrial workers.

Enough of nostalgia. What is meant by automation? It's not easy to define it or distinguish it from mechanization. Pretty clearly, the term means replacing some human performance with hardware or software. It is useful to consider what is replaced along two dimensions. One of these consists of the structural categories replaced. One category is human sensors, such as vision. Another is human effectors, such as hands or feet. A third is the central nervous system (CNS). In addition, there may be some combination of these. The other dimension is amount of performance. What is replaced may be a small element, or a task, or a function, or an entire operation.

These two dimensions not only help clarify what we mean by automation but also help decide what should be automated and what not and how human performance and machine performance should be related to each other and combined. Some sensor/effector element may be automated, as when an electric eye opens a door, within the sensor-effector task of walking through a doorway. The mainly-effector task of walking upstairs may be automated by installing an elevator, but some effector element of human performance may remain, such as punching a button for the desired floor. Automation may augment performance of the human or the human-machine combination; it may make it faster, more accurate, less effortful, more enduring. The automatic elevator is somewhat faster, certainly less effortful, and has much more stamina than the unaided individual. The direct contribution of automation should be distinguished from most human engineering design that occurs in the implementation of automation—for example, in the design of the control panel for the elevator.

Consider the automobile: the name itself signifies automation of mobility. As a system, it entirely replaces walking or running. But in contrast to the pilotless BOMARC, cruise missiles, and other RPVs, the automobile is a mix of automation and human performance, especially in the effector part of the system. The driver retains control through accelerator, brake, and steering wheel, but energy supply, propulsion and appendages (wheels) are, of course, automated. Long ago the automatic starter replaced hand-cranking; gasoline gauges replaced manually inserting a stick in the fuel tank; braking and steering may be power-aided; a turn indicator makes it unnecessary for the driver to signal with his hand; and some vehicles can be jacked up automatically for changing a tire. Many have automatic chokes. Voice-actuated controls are envisioned, as well as synthesized voice messages telling the driver to change the oil or adjust the brakes.

Less automation has occurred in the system's sensors. The driver's eyes and ears do almost all the work, though human vision is aided by headlights, windshield wipers, and rear view mirrors, and audition by curb-sensing antennas; and much aid to vision and audition comes from design features of the highway and other vehicles. In addition, some police cars have radar, which in futuristic designs has been projected for collision avoidance (radar braking systems) in ordinary vehicles; and CB radio can augment human auditory sensing.

There has been still less automation of the driver's CNS. Other than mechanical integration of clutch, gear shift, and acceleration in automatic shifting and electronic microprocessors for cruise and skid control and fuel economy (and eventually monitoring engine performance and tire pressure), it remains the human operator who acquires and maintains a store of prior experience to change sensory inputs into pattern perception, who does the tracking that keeps the automobile on the highway and avoids other vehicles, and who selects a route. (Admittedly, efforts have been made to provide route guidance from an external automated CNS, a computer.) The automobile system has no automated integrative capability to link sensor inputs and effector outputs. How much further can the automobile be automated? I'll return to that briefly later. My aim to this point has been to illustrate the complexity of automation as a concept—the difficulty in knowing where to draw the line in defining it—and to suggest that the automobile system nicely represents human-machine symbiosis, a notion to which I'll also return.

When is technology, or mechanization, not automation? We can try to follow our earlier prescription, that it replaces some human activity. In this sense, technology that simply augments what a human does is not automation. A microscope or telescope (or spectacles) would not be considered automation, since visual sensing still occurs with such devices. Nor would swim fins or the telephone; swimming or talking still

accompanies these. An individual can see more items, swim faster, and talk over longer distances with such devices but they are not substitutes. Non-substitute devices can also be imagined that would degrade rather than augment performance—for example, that would occlude vision. These also would not be regarded as automation.

Along another line, technology produces mechanisms which, because they can do things a human cannot, do not replace human activities and thus are not automation. Radar sensing makes use of part of the electromagnetic spectrum inaccessible to human sensing. Airplanes fly; people don't. But there's a slight problem. It concerns how one specifies what a person can or cannot do. A magnetic compass provides more precise geographical orientation than an individual can achieve just by visually sensing the sun or stars. A steamship travels greater distances than one can swim. A forklift raises weights a human cannot. A rifle shot can be more deadly than a stone But humans do orient themselves, swim to a far shore, lift packages, kill at a distance. A calculator can add or subtract faster or more accurately than I can, depending on the task, but I can do arithmetic. A computer, the epitome of automation, can perform more calculations in seconds than any one person could in a lifetime, but its component processes resemble a human's, as does its memory.

Even in the case of the automobile, it could be argued that though it replaces walking or running, its occupants are still going from here to there. It does not substitute for human "travel"—it simply makes it faster and extends its range. (The same could be said about the airplane.) Thus, if human performance is specified in general enough terms, much of what we call automation augments performance, rather than supplants it. The distinction between automation and other mechanization becomes blurred. Where to draw the line?

One must also consider second-order automation, such as automatic speed control in an automobile or the automatic pilot in an aircraft. Choices between second-order automation and manual operations, within first-order automation, have particular interest for engineering psychology.

What we call emotions and motivations would seem to fall outside the province of automation. But do they really? Might not machines be designed to express emotions—as, for example, in a computer's software-originated messages on a cathode ray tube? Might machines be given, in some fashion, incentives and deterrents (and even deprivations and aversive conditions of some kind) as motivational variables? In any case, machines do figure in emotional and motivational contexts. They can generate inconvenience, discomfort, effort, and stress, mild or severe: torture machines have at times replaced the bare fist to inflict pain and induce confessions from humans through escape from the device or its avoidance. Modern arcade games bring joy to child and adult alike. In operant conditioning, grain is automatically given to the pigeon that pecks a disk, pellets to the rat that presses the lever, as motivational incentives or reinforcers.

Is "automation" simply in the mouth of the speaker, like "beauty in the eye of the beholder"? In one of the few engineering psychology explorations of automation, Corwin Bennett (1973) almost a decade ago asked members of the Human Factors Society to rate 25 human functions on 12 scales which included the desirability, feasibility, and performance quality of machine substitution. He then factor analyzed the data obtaining one factor "automation" indicating "automatability" and another factor of "humanness," which had "high loadings on complex activities of people." Procedural, routine activities such as sorting mail, driving a car, and flying an aircraft had high loadings on the automation factor; social and cognitive activities had low loadings. For the "humanness" factor, writing novels, having sexual relations, treating ailments, and bearing

children were among those activities with high loadings, whereas physical work had negative loadings. Bennett also asked his respondents to select their "personal choice" and their understanding of common practice from among ten bases for deciding how much should be automated in a new version of a system. According to his rank ordering of selections for "degree of humanness," most of the personal choices ranked high for this attribute, but most of the common practices ranked low.

Why is automation an even more significant field for engineering psychology than it was a decade ago? After all, even before that time there was a Department of Defense requirement, in milspec MIL-H-46855, to allocate functions between operator and machine, that is, performance between human and automation, in the development of new military systems. In retrospect, this requirement has been satisfied only ritually—that is, after the fact. Decisions as to what should be automated and what should be performed by people have been made in the conceptual phase of system development, or even earlier, but without human factors inputs. The detailed allocations stemming from such early decisions have indeed been described in response to MIL-H-46855 but those responses did not guide the decisions. I believe there have been a number of reasons. First, the military planning agencies making trade-off decisions had no professional human factors participants, and human factors personnel in industry were rarely consulted during early system planning or exerted little influence. Second, the function allocation requirement was placed in a managerial specification for human engineering, but human factors engineering knowledge could supply only half the answer. As I said at the outset, any inquiry into some particular automation should study its advantages and limitations (and costs and feasibility) as well as those of humans. Few if any human factors engineers can be experts in the manifold technologies that can provide potential automation. Two sets of experts are needed—human performance experts and machine performance experts. Third, we haven't known enough about how to make allocations of functions or trade-offs between people and hardware/software, in dealing with system concepts. Fourth, the notion of "function allocation" is only a partial solution to the problem. System functions can represent too broad a subdivision of system performance; tasks and task elements must be considered, too. When this is done, it becomes necessary to emphasize combining human performance and automation in various ways.

Let me elaborate on my third point, insufficient knowledge for choosing between human and machine (or combining them). What guidance is there? I believe it is limited to the MABA-MABA lists (men are better at, machines are better at) put together over the years by Lyman and Fogel (1961), Chapanis (1965), Fitts (1951, 1962), Meister (1964), and others, and published in texts by McCormick (1970) and most recently, Hughingson (1981). These are useful as broad-brush heuristics but inadequate in themselves or by themselves. In themselves they fail to indicate, with regard to human advantages and disadvantages, the considerable variation due to (1) differences in skill levels dependent on selection; (2) potential changes in such levels due to training; (3) differences in performance due to motivational variables; (4) differences in performance resulting from good or poor design of hardware and software through human engineering; and (5) variance in performance according to the procedures used. Similarly, the guidelines usually disregard variation in machines due to unreliability and poor maintenance, development time requirements, expected advances in technology, and organizational or designer competence. These guidelines also fail to indicate how they can be combined in some aggregated estimates of human performance or of automation in some element, task, or function, and then what kind of metric might be used to compare these aggregates. By themselves, the lists are inadequate for dealing with a particular system, component, or problem. What is missing, for example, is a data base of past experience in both human performance and automation in similar systems,

components, and problems, as suggested by Price et al. (1980). In some fashion, these abstractions have to be related to subject matter. Testifying to their inadequacy is the lack of any evidence in the texts where they appear that they have actually been used effectively in major design decisions in system development, though such decisions, to be sure, have not been well-documented in general human factors texts.

But let's get back to my question, why automation is an even more significant field for engineering psychology today than earlier. In my own experience in varying degree during the last two years, I've encountered automation issues in half-a-dozen areas: command and control systems, robotics, combat aircraft, air traffic control, nuclear power plants, and the office of the future; such issues have developed elsewhere, of course, as in the postal service. Let me review some of the areas I've mentioned.

Together with my engineering colleague Jack Short I recently completed a study of command and control systems for the Air Force's Human Resources Laboratory (Short and Parsons, 1981). Though the study was directed at team performance, it necessarily considered automation. Such systems are being automated in varying extent in sensors (e.g., new radar and infra-red technology), in effectors (e.g., data link communications), and in central nervous systems (e.g., both large computers and microprocessors). Some systems are simply adaptations of older ones: the AWACS is essentially a small, improved, airborne version of a SAGE direction center together with a long-range radar. Procedures and training for teams as well as individuals must be investigated and optimized so operators will deal most effectively with this new or adapted automation. In addition, as Marty Tolcott pointed out earlier at this APA meeting, aids must be developed to help decision-makers, and these can take advantage of automation. Simulation-based team training can also be automated. Inputs can be presented and outputs recorded and evaluated automatically; an expensive host of observers and recorders should no longer be necessary. But the most interesting question is, in the new tactical command and control systems, what should be automated, what left to human performance? Essentially, few engineering psychologists or human factors engineers have been drawn into the discussion.

The operational command is as cautious about all-out automation on the ground as it is about all-out automation aloft. If only for that reason, system developers have adopted an "evolutionary" approach—in contrast to the revolutionary change embodied in SAGE. But their goal is the same. The president (Everett, 1981) of the largest development agency for Air Force C^2 systems recently complained that "computers have not been used to replace the staff; they have been used to augment or assist it. . . . Looking further into the future, much work needs to be done on finding ways to replace all kinds of people with machines in carrying out C^3 functions . . . The problem with the staff is not how to help the staff but how to get rid of the staff." (He was also appropriately concerned with the need to distribute people, processors, and data bases to make them less vulnerable, and he called for research in "how to distribute the staff function itself" and "how to use computers to support the commander directly rather than the commander's staff.") I think the point is that he emphasized replacement of staff with no mention of studying the best combination of staff and computer operations. To my knowledge, no one has done this, or done it adequately. Staffs are teams. Most human factors studies in C^2 have addressed individual performance related to the design of computer software and displays/controls. It seems to me here is an excellent area for military laboratories to investigate.

Before I move on from command and control systems to robots, I'd like to show you, in Table 1, Tom Sheridan's (1980) list of levels of automation or options for dividing work and responsibility between human and computer in decision-making. I think it has applicability to command and control as a sort of general heuristic. It

certainly does illustrate the varying kinds of symbiosis that can be designed into a system. (Incidentally, item 10 for 100% computer control might better omit telling the human anything.) The first analysis of this sort, I believe, came from Hanes and Gebhard (Parsons, 1972) in 1966 at the Applied Physics Laboratory, in their experimental research on Navy command and control.

Table 1

Levels of Automation in Decision Making

(From Sheridan, 1980)

100% Human Control	1.	Human considers decision alternatives, makes and implements a decision.
	2.	Computer suggests set of decision alternatives, human may ignore them in making and implementing decision.
	3.	Computer offers restricted set of decision alternatives, human decides on one of these and implements it.
	4.	Computer offers restricted set of decision alternatives and suggests one, human may accept or reject, but decides on one and implements it.
	5.	Computer offers restricted set of decision alternatives and suggests one which it, the computer, will implement if human approves.
	6.	Computer makes decision and necessarily informs human in time to stop its implementation.
	7.	Computer makes and implements decision, necessarily tells human after the fact what it did.
	8.	Computer makes and implements decision, tells human after the fact what it did only if human asks.
	9.	Computer makes and implements decision, tells human after the fact what it did only if it, the computer, thinks he should be told.
100% Computer Control	10.	Computer makes and implements decision if it thinks it should, tells human after the fact if it thinks he should be told.

Sheridan's analysis came not so much from the study of command and control systems as his investigations of teleoperators and robots. Several weeks ago, with my HumRRO associate Greg Kearsley, I did an investigation of human factors engineering in robotics, for the Army's Human Engineering Laboratory (Parsons and Kearsley, 1980).

I first became involved in robotics in a small study that Lew Hanes (1980) piggybacked on a National Science Foundation-Westinghouse project called APAS, for Adaptable-Programmable Assembly System. That project tackled one of the more challenging problems in robotics, to automate the assembly of a product, in this case small induction motors, that had many variations in design during the same time period. This is called "batch" manufacture, in contrast to mass manufacture of many more very similar items in a product line. No human factors engineering has actually been done in APAS, though some was projected by the Hanes add-on study, which primarily looked at organizational, occupational, and societal impacts. There has been a modest human factors engineering participation in the Air Force's ICAM (Integrated Computer-Aided Manufacturing) program, but as far as I've been able to judge, it has been a relatively conventional analysis of a new hardware/software system. Sheridan's work in teleoperators at M.I.T. (Sheridan and Verplank, 1978) and related research at the Jet Propulsion Laboratory (Bejczy, 1980) probably have come the closest to bringing human factors engineering to robotics, especially through the concept of "supervisory control" in which the teleoperator can function autonomously for short periods and in limited circumstances by having its own small processor linking sensors and effectors.

What is a robot? How does it differ from a teleoperator and from other kinds of automation? To some extent, the meaning and the distinctions, as for automation, are in the mouth of the speaker. Machines are called robots which seem to look and act like people. A complete robot would have all three categories of non-human structures replacing human structures: sensors for vision, audition, touch, proprioception; effectors for manipulation and locomotion; and a processor for at least coordinating these other categories, with stored instructions and data that would permit the robot to adapt to minor deviations and that could be programmed so the robot would respond differently and appropriately to a considerable variety of objects and situations and their presentations. The more versatile the sensors and processor, the more "human-like" the machine would seem, and thus the more likely to be called a robot. Effector arms and hands must be able to grasp and move objects, even if they lack fingers. Effectors for locomotion must resemble legs and feet; an automobile or anything with wheels would be less likely to be called a robot, though the term has been used for vehicles exploring Mars. A machine sensor by itself, such as radar, or a processor in itself, such as a computer, is not called a robot. Increasingly, however, the programmable processor is being required in defining something as a robot. Teleoperators are not called robots because a human operator remains in the loop, even in Sheridan's supervisory control. Such automation as process control in refineries and power plants has a programmable processor and various sensors but lacks human-like effectors. In ordinary numerical control of machine tools, there is no visual or auditory sensor and the processor is punched paper tape; in subsequent direct numerical control and computer numerical control, the processor has become a minicomputer or dedicated microprocessor controlling more than one machine tool station. Process control and numerical control are not subsumed under robotics, nor are the moving assembly belts and other long-present forms of factory automation.

I've gone into such detail in describing the niche robots have in automation because I believe there's some confusion about it. One reason for our review for H.E.L. was to acquaint the engineering psychology community and the human factors engineering community with robotics and the role people in these communities might play in this new field; we hope to publish our review in a journal shortly. As far as I know, only one such effort has been made previously, by Gavriel Salvendy and his associates at Purdue (Kamali, Moodie, and Salvendy, 1981; Nof, Knight, and Salvendy, 1980). They developed a "job and skills analysis" approach in which the relative abilities of humans and current

industrial robots are compared in considerable detail, within the categories of "(a) action and manipulation, (b) brain and control, (c) energy and utility, (d) interface, and (e) miscellaneous factors." With relative abilities constituting one of the criteria for deciding between human and robot performance, they determined which should be selected for each of the task elements in assembling a water pump.

After examining the literature and interviewing a number of robot developers and users, Kearsley and I took a somewhat different approach by identifying nine types of human performance that are likely to be required for any industrial operation that might involve robots. We have shown that humans are currently engaged in all of these, in roboticized operations, and we have suggested that humans and robots will continue to perform jointly within each type—though one or the other may act alone—and that humans and robots should perform symbiotically within the entire set of nine types. Ours is called the SIMBIOSIS model (misspelling intentional). The nine types of performance are surveillance, intervention, maintenance, backup, input, output, supervision, inspection, and synergy.

Surveillance means, of course, monitoring. Intervention by humans can consist of set-up, start-up and shut-down, programming and reprogramming, on-line editing, and taking corrective actions. Maintenance involves both hardware and software; robots do need it. Manual backup may be essential to keep a factory running. Input is especially important for feeding parts initially into an automated assembly operation. Output includes dealing with rejects. Supervision involves planning and coping with emergencies. Inspection occurs in both processing and quality control. Synergy, illustrated by supervisory control in teleoperators, means that human and robot working together in an operation do better than either alone; in an assembly operation, for example, some components can be handled better by a robot, some better by a human.

Just how well a robot can do something will keep changing as robots are improved, especially in their sensors (visual and tactile) and processors (software). Scientists in the field of artificial intelligence are trying to help robot manufacturers improve them; how fast progress will be made and how far it will reach is, as you might expect, essentially uncertain. The division of labor between robot and human will change as robots become smarter and more skillful, no longer as unable to do what humans can do. But there are other criteria for selection: (1) a robot does what humans don't or cannot do; (2) a robot does what humans are not available for doing; (3) a robot does what humans do but shouldn't do (e.g., because of danger or undue exertion); (4) a robot does what humans do but does it better; and (5) a robot does what humans do but does it at less cost.

Beyond these human factors engineering and other criteria are questions of occupational, organization, and societal impact, short term or long term. In the short term, jobs will change or disappear and productivity may increase. In the long term, robots may become the slaves of our culture, doing the work that, deep down, almost everyone would avoid doing if that were feasible.

Making selections between robot performance and human performance and combining them symbiotically are not the only prospective human factors involvements in robotics. New jobs must be designed for people, new procedures developed, new training created, new human engineering applied to the control panels and software that people will use in any roboticized operation. Organizational change and human satisfaction are still other considerations. The Human Resources Research Organization has established a Center for Robotics to study such effects as well as human factors engineering in robotics. But to me personally symbiosis is the most interesting challenge. Kearsley and I did not create the human-machine application of thir term. J.C.R. Licklider (1960)

did it years ago, and more recently it was used by Joseph Engelberger (1974), president of Unimation, the largest manufacturer of robots. Charles Rosen, president of another robot firm, has strongly endorsed the concept (personal communication). The concept has been recently advocated with respect to automation by Hopson, Zachary, and Lane (1981).

If robotics is a new enterprise for engineering psychologists, piloting combat aircraft is one with a longer history. Yet I believe the first full-fledged confrontation with automation in such aircraft took place this July in a Summer Study at Wood's Hole, held by the Air Force Studies Board of the National Research Council, which is an arm of the National Academy of Sciences and National Academy of Engineering. Automation has been proceeding apace in fighter aircraft, such as the F-15, F-16 and F-18, and new systems have been developed such as DAIS (Digital Avionics Integrated System) to help implement this and future automation; human factors engineering has been applied to the implementations, but no one, at least for the record, has systematically asked, what should be automated, what should the pilot still do? No one did so, that is, until the commanding general of Air Force Systems Command sat in a DAIS simulator and received verbal orders, on a CRT, telling him, a four-star general and former fighter pilot, just what he should do next. He asked the Air Force Studies Board to undertake the Summer Study, in which there was a technology group, that looked at current and potential technology for automation; a human factors group, that pondered what should be automated and why, and a functions group, that established or elaborated on a framework for the other two. I took part in the human factors group. delighted that this much recognition had come to our field, that automation was being examined as a matter of human factors concern, and especially that the Summer Study was a multi-disciplinary, multi-group effort—as I indicated at the beginning of this talk studies of automation should be.

Probably the mere fact that such a study was conducted was the most important thing about it. One shouldn't expect too much from twenty working days, half of which were devoted to briefings. I might mention some aspects of the study if only to indicate how difficult it was to get a handle on issues of automation in combat aircraft or elsewhere.

1. It was assumed there would always be a pilot in such aircraft. Though there was a briefing on RPVs, these were not otherwise considered.

2. The study did not take up the issue of one versus two persons in the crew station, though including a second person has been discussed as an alternative to automation for reducing individual workload.

3. Since the study was unclassified, relatively little attention was given to electronic warfare, despite its significance for pilot workload and automation. Since I've always been concerned about man-made "noise," I found this omission especially regrettable, though not surprising.

4. Air-to-air combat was the primary focus. Partly because air-to-ground operations received less emphasis, pilot interaction with ground command and control also was underemphasized. Again I was not surprised. Agencies of Air Force scientists, engineers, and military developers interested in new aircraft have shown too little regard for ground-based systems.

5. The Technology Group seemed to be intrigued more with what new automation technology was feasible and what forms it might take than in whether it was desirable and what criteria to apply to decisions about automation.

6. Virtually no one in the entire study had ever heard of MIL-H-46855 or was aware that tradeoff analyses between automation and human performance in weapon system development had been required by the Department of Defense (and thus by the Air Force) for many years.

7. The half-dozen members of the Human Factors Group during the discussion/report preparation phase of the study included no one who had had pertinent human factors engineering experience with combat aircraft, though one member, Ren Curry of NASA, had investigated automation in commercial aircraft; you may have seen his publications with Earl Wiener (Wiener and Curry, 1980). But we were fast learners, profiting from the briefings.

Essentials of one briefing, by the Tactical Air Command, were incorporated into the Human Factors Group report as constituting a sort of self-report automation survey of Air Force system users; such surveys are, of course, a standard way to initiate a human factors engineering study. We also got consulting help from several individual fighter pilots, though they were not always in agreement, and we examined several aircraft, including an F-16 flown in to Otis Air Force Base for the purpose.

Since the chair of our group, Stu Card, was a cognitive psychologist active in artificial intelligence, our report (Card et al, 1981) stressed the cognitive skills a fighter pilot should have and likened the in-the-head ("mental") representation he should acquire about a dogfight to the representations a chess master should have in a chess game; in each case what is needed are "situational awareness" and planning a number of moves ahead, based on hundreds or thousands of hours of practice. Though at heart I'm a behaviorist and value also a pilot's psychomotor skills, I really believe engineering psychologists should become better acquainted with the field of artificial intelligence. We should ask what we can learn from it to apply in combat automation or elsewhere, if only because AI is basically computer-oriented, and aircraft systems are increasingly computer-controlled. (Just as engineering psychology should look to AI/cognitive science for insights as to how, and how well, humans perform, it should draw on behavior analysis/operant conditioning for understanding as to why, and whether, they do things—that is, for examining motivational variables, with regard to automation or otherwise.)

Our group's report included a number of general guidelines about automation selection and implementation that I don't have time to go into here; in large part they resembled what Curry and Wiener had proposed earlier; and as I indicated, it summarized TAC's views. It also reviewed pitfalls in automation, including the issues of complexity/reliability/maintainability, user acceptability, unintended use, system failure, rigidity/flexibility/modifiability, and unpredictable consequences, as well as loss of manual skills and need for transition training. One kind of automation that especially intrigued me was the computer-based integration of two or more systems in the aircraft, such as sensors, navigation, and flight control (an effector system) in low altitude terrain-following and avoidance at night. Prior to such automated integration it was the pilot who had to accomplish it (like the controller of a teleoperator, in a sense). The systems integration can be presented to the pilot to monitor on an integrated display, but this is somewhat different from a joint display of tasks the pilot himself has to integrate.

Any kind of display which helps an operator perform a control or decision task by itself performing some of that task—as a joint display might perform some integration or a predictor display might replace his in-the-head planning—can be regarded as a kind of automation; machine performance replaces some human performance. But most human engineering of displays and controls, in the crew station or otherwise, does not fall into this category. It improves or augments human performance without taking something away; and it may do this in <u>implementing</u> some kind of system automation through properly designed displays and controls required by the automation. In the Summer Study, it seemed to me that some of the engineers in the technology group viewed this as the expected role of human factors engineering—the cockpit implementation of automation; they were properly concerned lest some automation fail or do

poorly because the pilot interface was maldesigned. It may take some time to modify this limited understanding of the role of human factors engineering in automation.

When I reflected back on the study of human factors engineering in the Air Force I helped conduct in 1979-1980 (Parsons et al, 1980), I realized that we had not really dealt with automation as inherent in function allocation or person-machine symbiosis, though we acknowledged the requirement for front-end analysis in system development. Nor did we specify the need for a multi-disciplinary technology to apply to automation issues in a system's concept phase. One of our Summer Study recommendations was to encourage the Air Force to develop such technology. Another need is to extend the requirement to analyze automation decisions beyond the human factors engineering mil-spec and to include in such analyses specialists in both human factors engineering and in advanced engineering technology.

Well, this has been a rather personalized account of several recent, significant (I think) developments in automation of interest to engineering psychology. I don't have the time to get into the others I mentioned—air traffic control, nuclear power plants, and office automation, nor have I had as much involvement in them. Let me finish by speculating about what I think the automation issue means for the future of engineering psychology.

For one thing, engineering psychologists have to become involved in this issue whether they want to or not, or they will indeed face technological unemployment. Whether or not to automate, and what happens if you do, is increasingly the name of the game. I'm certainly not the first to bring up this question. Jordan (1963) and Melching (1968), as well as those cited earlier in discussing MABA-MABA, pondered the problem, and more recently Price et al. (1980) have emphasized it. I believe the main thrust should take the form of symbiosis—the combination of automation and human performance. In research, engineering psychologists should examine human performance that is difficult to automate, to be able to describe its advantages in symbiotic relationships. But to know what is difficult to automate, they must learn quite a bit about automation technology. Since so much of this lies now in the category of replacing the human central nervous system by computer processing, they must learn a lot about such processing, especially in artificial intelligence. In applications, engineering psychologists will have to work closely with engineers and programmers in planning new systems; I have already emphasized this point. The human factors team should include experts in human capabilities and limitations, in the distribution and training of skills, in the development of procedures, and in the human engineering design of hardware and software. Only thus can engineering psychology effectively enter system development at the front end.

In thinking about command and control systems, robots, and combat aircraft, I've been struck by one outstanding obstacle to automation: the infinite variety with which it must cope. Some of this is created by a hostile force. Most consists of the manifold differences among objects, environments, and people, but much comes from the different ways these present themselves for sensing and the differences within sensing agents in capacities or prior experience and learning. An apparently infinite variety exists too in operations on the external world, by effectors, whether hands or language.

We remain relatively unaware of such variety until we try to replace the human with some kind of automatic device. There seem to be two ways for automation to confront variety. One is to constrain it. The more constrained the variety in input and output, in information theory terms the less the information, the easier it is to design suitable automation. The other is to understand how human beings handle this variety; then it may be possible to design automation to do better than it has—or it may become clear, where automation will never be able to match humans.

A simple illustration of constraint is the difference between checkers and chess. The first has a relatively limited number of players, positions, and moves. The second also has a limited number of positions but a variety of players and a variety of moves. By "brute force" a computer can beat a human at checkers and many humans but not grand masters at chess. Yet chess is still a constrained world and effector requirements are modest; even today a robot could be designed to pick up the pieces and move them. Neither checkers nor chess exemplifies the infinite variety of the real world. Could the most sophisticated robot ever drive an automobile successfully in rush hour on the Santa Monica freeway or across town on regular streets in traffic? Could it climb a mountain or traverse a jungle? Could it give a talk at the APA? I like my automobile example the best. With it we can apply the so-called Turing test. If ever an automobile can proceed without a driver or external control from downtown Los Angeles to the middle of San Francisco, artificial intelligence will have shown that automation has no limits.

How do people manage to do complicated things? No two visual inputs are ever precisely the same, nor two outputs. Life would be impossible were it not for the phenomenon of generalization (which in turn produces verbal concepts or categories). Thus, in a sense, human behavior imposes constraints on itself to cope with the world's infinite variety. This is the kind of basic human phenomenon that engineering psychologists might investigate to understand how humans can often process inputs and arrange outputs better than computer software with its associated sensors and effectors. As far as I know, neither cognitive psychologists nor investigators in artificial intelligence have paid it much heed.

Other basic research can be addressed to the criteria to apply in making choices between automation and human performance. For example, to what extent should performance be automated simply because such performance is effortful or inconvenient—such as brushing one's teeth or fastening one's seat belt. Effort and inconvenience as motivational variables—deterrents or disincentives—that automation might diminish in influence have received very little attention, presumably because they involve behavior analysis or operant as well as engineering psychology. What is lost, if anything, through too great a reduction in effortful behavior?

On a more applied level, engineering psychologists should join with engineering technology developers to devise techniques for comparing human performance with machine performance, doing trade-off studies, and combining the two kinds of performance, as I've already indicated. Some general guidelines have been ventured by Chapanis (1960), Corkindale (1967) and Price et al. (1980). Applicable techniques and metrics should be added to the technology of human factors engineering surveyed in 1979-1980 by Williges and Topmiller (1980).

Also on a more applied level, research in engineering psychology should examine the effects of automation—not so much those that organizational psychologists or sociologists may study but some that are closely tied to system operations or involve effects on system operators. Consider, for example, information feedback. Humans in the automation loop are more likely to get such feedback about their own performances from machines than from other people. What difference does that make? With automation it becomes easier to monitor performance and display information feedback about such performance. How can beneficial effects of this be assured and negative effects (e.g. stress from being monitored) be avoided?

If automation is going to require placing more and more constraints on inputs and outputs so more and more things can be automated, as I predict, how will such simplification and standardization affect people, whatever roles they may have? New jobs

have to be designed. As Corwin Bennett (1973) and Bob Ford (1969) have suggested, engineering psychologists should become involved in job design, not just in task design. Can jobs be designed so they provide feedback as work incentive and to produce satisfaction, or so they maintain skills to use in emergencies? Perhaps engineering psychologists should try to predict effects of automation such as the increase in paper flow resulting from copiers, despite forecasts that new technology would bring us a paperless world. Above all, in specific applications of automation, engineering psychologists should try to develop the best divisions of labor between human and machine, the optimal combinations. We should not leave the field either to those who would automate for automation's sake or to those who worry that people are going down the drain.

In conclusion, let me cite Norbert Wiener in *God and Golem* (1964). He wrote that one of the great future problems we must face is how men and machines must interact and which functions properly belong to each; there should be, he said, a creative symbiosis of man and machine.

He was right.

REFERENCES

Bejczy, A.K. Sensors, controls, and man-machine interface for advanced teleoperation. *Science*, 1980, 208, 1327-1335.

Bennett, C.A. The human factors of work. *Human Factors*, 1973, 15, 281-287.

Card, S.K., Berry, C.A., Curry, R.E., Hennessy, R., Licklider, J.C.R., Parsons, H.M., Swezey, R.W., and White, C.S. *Human Factors Subcommittee Report, Summer Study on Automation in Combat Aircraft.* Washington, DC: Air Force Studies Board, National Academy of Sciences, 1981.

Chapanis, A. Human engineering. In C.D. Flagle, W.H. Huggins, and R.H. Roy (Eds.), *Operations research and systems engineering.* Baltimore: Johns Hopkins Press, 1960.

Chapanis, A. On the allocation of functions between men and machines. *Occupational Psychology*, 1965, 39, 1-11.

Corkindale, K.G. Man-machine allocation in military systems. In W.T. Singleton, R.S. Easterby, and D.C. Whitfield (Eds.), *The human operator in complex systems.* London: Taylor & Francis, 1967.

Engelberger, J.F. Man-robot symbiosis. In *Proceedings of the Fourth International Symposium on Industrial Robots*, 1974.

Everett, R.R. Command, control, and communications. *The Bridge* (National Academy of Engineering), 1981 (Summer), 11(2), 17-25.

Fitts, P.M. (Ed.) *Human engineering for an effective air navigation and traffic control system.* Washington, D.C.: National Research Council, 1951.

Fitts, P.M. Functions of men in complex systems. *Aerospace engineering*, 1962(1), 21, 34-39.

Ford, R.N. *Motivation through the work itself.* New York: American Management Association, 1969.

Hanes, L.F. *Report of the Committee to Define Worker-Related Research for Adaptable-Programmable Assembly Systems.* Pittsburgh: Westinghouse R&D Center, 1980.

Hopson, J., Zachary, W., and Lane, N. The intelligent use of intelligent systems: Problems in engineering man/machine symbiosis. Paper distributed at the Summer Study on Automation in Combat Aircraft, 1981.

Hughingson, R.D. *New horizons for human factors in design.* New York: McGraw-Hill, 1981.

Jordan, N. Allocation of functions between man and machines in automated systems. *Journal of Applied Psychology*, 1963, 47, 161-165.

Kamali, J., Moodie, C.L. and Salvendy, G. A framework for integrated assembly systems: Humans, automation, and robots. In *Proceedings of the 2nd International Conference on Assembly Automation*, Brighton. UK, 1981.

Licklider, J.C.R. Man-computer symbiosis. *IRE Transactions on Human Factors in Electronics*, 1960, 1, 4-10.

Lyman, J. and Fogel, L.J. The human component. In E.M. Grabbe et al. (Eds.), *Handbook of automation, computation and control*, vol. 3. New York: Wiley, 1961.

McCormick, E.J. *Human factors engineering*. Third edition. New York: McGraw-Hill, 1970.

Meister, D. Methods of predicting human reliability in man-machine systems. *Human Factors*, 1964, 2, 621-646.

Nof, S., Knight, J. and Salvendy, G. Effective utilization of industrial robots: A job and skills analysis approach. *AIIE Transactions*, 1980, 12, 216-225.

Parsons, H.M. *Experimental laboratory studies of the AN/GPA-23(XW-1)*. Technical Report T-1/A-IV. New York: Columbia University Electronics Research Laboratories, 1954(a).

Parsons, H.M. *Field tests of the AN/GPA-23 (XW-1)*. Technical Report T-2/A-IV. New York: Columbia University Electronics Research Laboratories, 1954(b).

Parsons, H.M. *A rule-of-thumb method for determining the angle off the bomber*. Technical Report T-4/A-V. New York: Columbia University Electronics Research Laboratories, 1954(c).

Parsons, H.M. *The development and installation of a system training program: The SAGE ECCM model*. Report SP-265. Santa Monica, CA: System Development Corporation, 1960.

Parsons, H.M. *Man-machine system experiments*. Baltimore: Johns Hopkins Press, 1972.

Parsons, H.M., Hendrick, H.W., Jones, E.R., Short, J.E., Snyder, H.L., and Williges, R.C. *Human factors engineering in the United States Air Force*. Summary Report of the Independent Study Team. Submitted to Air Force Systems Command, 1980.

Parsons, H.M. and Kearsley, G.P. *Human factors engineering considerations for the planning, design and use of robots*. Report for the Human Engineering Laboratory, Department of the Army. Alexandria, VA: Human Resources Research Organization, 1981.

Parsons, H.M. and Sciorra, A.F. *Analysis and implementation of the GCI system—Laboratory testing and training program, tracking computing group, radar AN/GPA-23(XW-2)*. Final Report F/A-V. New York: Columbia University Electronics Research Laboratories, 1954.

Parsons, H.M. and Seiden, H.R. *Adaptation of the SAGE system training program to the electronic countermeasures environment.* Report TM-399. Santa Monica, CA: System Development Corporation, 1959.

Price, H.E., Fiorello, M., Lowry, J.C., Smith, M.G., and Kidd, J.S. *The contribution of human factors in military system development: Methodological considerations.* Technical Report 476. Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences, 1980.

Sheridan, T.B. Computer control and human alienation. Paper at the World Council of Churches Conference on Faith, Science and the Future at the Massachusetts Institute of Technology, 1979. *MIT Technical Review*, 1980, 82(4), 22-23.

Sheridan, T.B. and Verplank, W.L. *Human and computer control of undersea teleoperators.* Cambridge, MA: Department of Mechanical Engineering, Massachusetts Institute of Technology, 1978.

Short, J.E. and Parsons, H.M. *A proposed AFHRL research program in team performance in command and control (C^2).* Report submitted to the Air Force Human Resources Laboratory, 1981.

Wiener, E.L. and Curry, R.E. *Flight-deck automation: Promises and problems.* NASA Technical Memorandum 81206. Moffett Field, CA: Ames Research Center, National Aeronautics and Space Administration, 1980.

Wiener, N. *God and Goleme—a comment on certain points where cybernetics impinges on religion.* Cambridge, MA: M.I.T. Press, 1964 (pp. 83-84).

Williges, R.C. and Topmiller, D.A. *Technology assessment of human factors engineering in the Air Force.* Task III Report, for Air Force System Command, 1980.